Cloud Induced Polarisation in Aura MLS Radiances: Simulation and Observation

Cory P. Davis
School of Geosciences
University of Edinburgh

Jonathan H. Jiang, Dong L. Wu
NASA Jet Propulsion Laboratory

Claudia Emde
Institute of Environmental Physics, University of Bremen

We present a series of 3D polarised radiative transfer simulations made with recently developed Reversed Monte Carlo, and Discrete Ordinate Iterative radiative transfer algorithms, which are part of the ARTS-1.1.x software package. The software allows the study of the effect of horizontally aligned non-spherical ice crystals on Aura Microwave Limb Sounder (MLS) radiances. Simulation results are presented, indicating features we should see from MLS radiances for various cloud scenarios. These are compared with the initial data from the MLS instrument.

1 Introduction

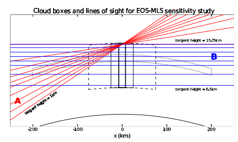
Microwave limb sounding trace gas measurements are less affected by clouds than remote sensing techniques using shorter wavelengths. However, thick cirrus will degrade upper tropospheric trace gas measurements, and on the other hand, cloud information can be retrieved (See Jonathan Jiang's poster!).

Although much can be learned about the effect of clouds on MLS radiances from a simplified unpolarised treatment using Mie theory, an accurate forward model can only be obtained with the consideration of polarisation. The work presented here represents the first attempt to simulate cloud affected MLS radiances using a fully polarised radiative transfer model.

Polarised radiative transfer calculations are performed by considering the full Stokes vector, $\mathbf{I} = [I, Q, U, V]$. In the context of Aura MLS, we are interested in the first two Stokes components $I = I_v + I_h$, and $Q = I_v - I_h$, because the radiometers have either H or V polarisation. In particular, for Radiometer 1 (118 GHz), we can directly measure the polarisation difference, Q, since we have both polarisations, R1A(V) and R1B(H). Also, we may be able to observe polarisation effects by examining the relationship between R2 (190GHz, V) and R3 (230GHz, H).

2 Simulations

For the following sensitivity study we have varied cloud dimensions, ice water content (IWC), and particle aspect ratio, while maintaining constant representative tropical water vapour and temperature profiles. The cloud types considered were chosen to represent a range of thin layer and tropical convective ice clouds. The thin layer scenario had a cloud-top at 13.4 km, a thickness of 1.5km and a width of 400km. Three deep ice cloud scenarios had a cloud top at 16km, a thickness of 10km and widths of 15km, 50km and 150km. For the thin layer cirrus simulations both ARTS-MC [1], and the 1D version of ARTS-DOIT [2] were used. For the rest of the cloud types, only ARTS-MC was used. IWC was varied from 0.01 gm^{-3} to 1.0 gm^{-3}. The size distribution of McFarquhar and Heymsfield (1997) was used to derive particle size distributions from local temperature and IWC. Particles were represented as spheroids, with aspect ratios ranging from 0.2 (prolate) to 5 (oblate). Particles were assumed to be horizontally aligned; this means that oblate particles had their axis of rotation parallel to the local zenith, and oblate particles had their axis of rotation perpendicular to the local zenith and were oriented randomly in the azimuth.



Two schemes were used for the placement of the sensor relative to the cloud, A and B. These are illustrated in Figure 1.

Figure 1. Cloud box sizes and lines of sight for RT simulations

3 Radiometer 1

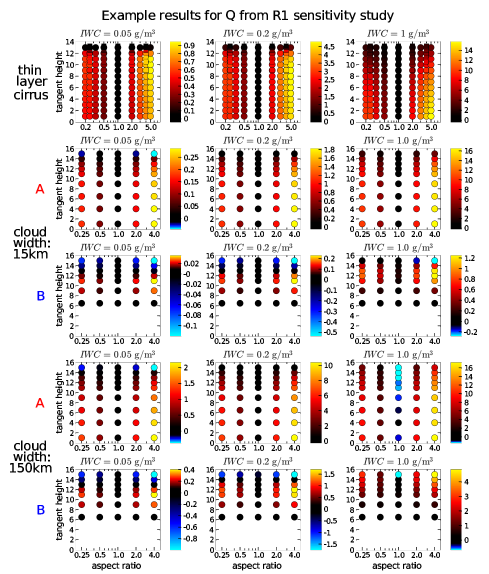


Figure 2. ARTS R1 simulations. This is a subset of simulated Q values of the MLS R1 sensitivity study.

R1 (118 GHz) offers the most straight forward study of polarisation effects, because both V(R1A) and H(R1B) polarisations are measured. However, R1 is not well suited to cloud studies because of the prominent O_2 spectrum; R1B was mainly intended as a back-up for temperature and pointing. In the following simulations and observations we consider band 32 (122GHz), which is the band furthest from the 118 GHz O_2 line.

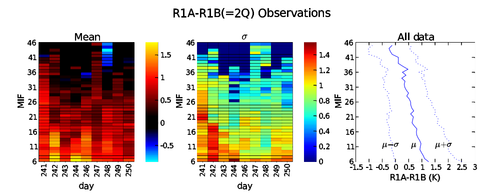


Figure 3. MLS R1 observations. Cloudy radiances were extracted from 9 days' data. Summary statistics for $R1A - R1B = 2Q$ are shown above.

Comments

- for R1 simulations, cloud induced partial polarisation is predominately vertical, though for the deep clouds viewed from the side (B), some partial horizontal polarisation occurs.
- Q polarisation signal increases in magnitude with IWC and cloud size.
- for the A viewing directions, Q tends to increase with decreasing tangent height.
- Big difference between A and B viewing directions, due partly to different optical path between the sensor and cloud.
- Observations agree with the predicted positive polarisation difference for low tangent heights, with Q becoming insignificant for high tangent heights. However, the noise in Q has a similar magnitude to the signal.

4 Radiometers 2 and 3

R2(190 GHz) and R3(230 GHz) are more sensitive to ice clouds than R1. Ice clouds can produce a brightness temperature depression of over 100 K for low tangent heights, and a brightness temperature enhancement of over 50 K for high tangent heights. Because R2 and R3 have different sensor polarisations (V and H respectively), the relationship between cloud-induced brightness temperature depression, ΔT_{cir}, measured by the two radiometers, c be significantly affected by oriented non-spherical part

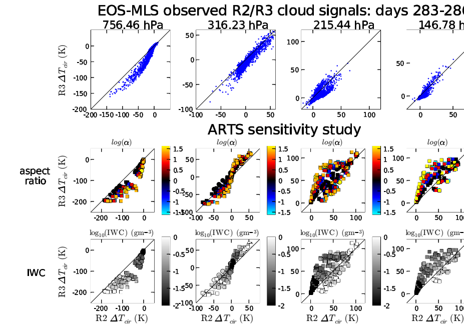


Figure 4. R2/R3 simulations and observations. Observa over 4 days of R2 and R3 ΔT_{cir} are shown in the top r plots for 4 tangent pressures. The equivalent plots for the sensitivity study simulations are shown in the nex rows. In the second row points are coloured accordi the particle aspect ratio. In the third row points are sha according to cloud IWC

Comments

The general form of the R2/R3 ΔT_{cir} relationship is re ably well replicated by the simulations for the lower tangent heights. The spread of points about the dia can be reproduced by altering the aspect ratio of the ice ticles; therefore the R2/R3 data is suggestive of the pre of horizontally aligned non-spherical scatterers. Howeve effect of changing clear sky atmospheric variables has y be studied.

5 Summary

Initial investigations of MLS radiances show rea able qualitative agreement with ARTS simulat for a range of cloud properties. Comparison of ulation and observation indicates that horizon oriented non-spherical particles are noticeably i encing the bulk scattering properties of ice cloud MLS frequencies. Further ARTS simulations data analysis are required to investigate the uti tion of MLS polarisation information.

Details

Why will clouds produce polarised radiances?

To understand this we need the vector radiative transfer equation, which describes the spatial variation of the Stokes vector in a scattering and absorbing medium.

$$\frac{d\mathbf{I}(\mathbf{n})}{ds} = -\mathbf{K}(\mathbf{n})\mathbf{I}(\mathbf{n}) + \mathbf{K_a}(\mathbf{n})I_b(T) + \int_{4\pi} \mathbf{Z}(\mathbf{n},\mathbf{n}')\mathbf{I}(\mathbf{n}')d\mathbf{n}'$$

s is distance along direction $\mathbf{n}$ and I_b is the Planck radiance. $\mathbf{K}(\mathbf{n})$, $\mathbf{K_a}(\mathbf{n})$, and $\mathbf{Z}(\mathbf{n},\mathbf{n}')$ are the bulk extinction matrix, absorption coefficient vector and phase matrix of the medium respectively. Ice particles in clouds are generally non-spherical and plates and columns will have a preferred horizontal orientation. This results in a non-diagonal extinction matrix, $\mathbf{K}(\mathbf{n})$, which is a source of polarisation (**dichroism**). In this case the horizontally aligned non-spherical particles have a negative K_{21}, which has the effect of vertically polarising radiation. The other main source of polarisation here is the scattering integral, $\int_{4\pi} \mathbf{Z}(\mathbf{n},\mathbf{n}')\mathbf{I}(\mathbf{n}')d\mathbf{n}'$. The sign and magnitude of this contribution depends on the angular distribution of incoming radiance, and the shape and orientation of scattering particles.

Software

Polarised RT calculations were performed using the ARTS-1-1-x software package. ARTS is a freely available collaborative open-source project; the package can be downloaded from http://www.sat.uni-bremen.de/arts/download.php. ARTS is uniquely suited to the simulation of limb sounding measurements in cloudy cases due to the accommodation of scattering, polarisation, and 3D spherical geometry. ARTS contains two scattering modules: **ARTS-DOIT [2]** – a discrete ordinates type model that can be used with 1D or 3D atmospheres, and **ARTS-MC [1]** – a reversed Monte Carlo model that can be used with only 3D atmospheres. For efficiency reasons ARTS-MC is preferred for realistic 3D cases. However, where a 1D approximation is appropriate, e.g. for extensive thin layer cirrus, the 1D version of ARTS-DOIT is preferable.

Acknowledgements

The work of CPD is funded by NERC, under the Clouds Water Vapour and Climate thematic program. Thanks are due to the entire MLS team, and also to the developers of the ARTS software package.

References

[1] C. Davis, C. Emde, and R. Harwood, "A 3d polarized r monte carlo radiative transfer model for mm and sub-mm remote sensing in cloudy atmospheres," *IEEE Trans. Geosci Sensing*, p. in press, 2004.

[2] C. Emde, S. A. Buehler, C. Davis, P. Eriksson, T. R. Sre and C. Teichmann, "A polarized discrete ordinate sca model for simulations of limb and nadir longwave measu in 1d/3d spherical atmospheres," *J. Geophys. Res.*, vol. i 2004.